

A. STUDY OF COSMIC AND LENARD RAYS

by

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STATEMENT OF PROBLEM

This thesis consists of reports on research carried out in two fields:

A. A study of cosmic rays by coincidence counter method.

B. A study of the effects of Lenard rays.

COSMIC RAYS

According to Compton (4), at the beginning of this century Wilson, Elster, and Geitel found that ordinary air, usually considered a good insulator, was slightly ionized even in the absence of any ionizing agent known at that time. This ionization was at first attributed to radioactive elements either in the earth or in the atmosphere. However, observations made from high towers by Wulf and Gockel in 1910, and from balloon ascensions by Hess and Kolhorster in 1912-1914, indicated an increase of ionization with altitude, rather than a decrease as had been predicted. These latter observers concluded that the ionizing source must enter the atmosphere from without.

In 1925 Millikan (12) confirmed the cosmic

origin of this penetrating radiation by electroscope measurements made below the surface of Lake Muir in California. They found a decrease in radiation with increasing depth until at 60 meters ionization became constant at the very low value of 1.1 ion-pairs per cubic centimeter per second.

Since 1925 interest in and investigation of cosmic rays has progressed rapidly. Scientists have carried apparatus to many parts of the earth in an effort to learn more about these highly penetrating radiations, but there is still much controversy as to their actual nature.

The different kinds of particles and radiations observed at the surface of the earth are probably of both primary and secondary origin. Millikan (12) assigns 75 to 85 per cent of the total ionization to secondaries produced within the atmosphere. By a study of this mixture of primaries and secondaries, scientists hope to solve the mystery of the nature and source of the primary beam.

In a theoretical discussion of the constitution of cosmic rays, Swann (23) lists nine entities which demand consideration: the electron, the proton, the positron, the neutron, the photon, the deuteron, the hydrogen particle, the alpha particle, and nuclear entities of various kinds usually regarded as composed in some way of the first four

fundamental entities listed. To this might be added the new particle recently reported by Anderson and Neddermeyer (34) in connection with their cloud chamber measurements.

In experimental studies of the composition of the cosmic ray beam, there is much controversy and apparent contradiction among investigators. They agree that the electron and positron are definite components forming by far the larger portion of the total radiation. Observers also agree that there is a proton fraction present at sea level, but the assigned per cent composition varies. The lowest figure, less than five per cent, is given by Montgomery et al (15), the highest, 12 per cent, by Millikan (12). Rumbaugh and Locher (18) have concluded that the primary beam is made up largely of neutrons having practically no ionizing power. Cloud chamber photographs show evidence of photons within the cosmic ray beam. Tracks below a horizontal lead shield within the chamber have been observed which had no apparent source above the shield. These tracks must be due to charged particles emitted from the lead by action of a non-ionizing photon which entered from above. Further study of cloud chamber photographs has shown a small alpha particle component. Important evidence concerning alpha particles was recorded

4

by photographs made during a stratosphere flight (24) in 1935. The apparently secondary nature of these alpha particles was indicated by their absence in the upper atmosphere. The horizontal direction of nearly all of the alpha tracks noted gave added indication of their secondary origin. Direct evidence has been obtained (25) of hydrogen or helium atomic nuclei tracks on fine grain photographs. A new entity component recently suggested by Street and Stevenson (21) is an unusually penetrating particle, neither electron nor proton, which, according to their report, makes up about 80 per cent of the sea level beam. This probably is identical with the particle recently reported by Anderson and Neddermeyer (28.) which has a mass about half-way between that of a proton and that of an electron, a charge equal to that of an electron, and of which both positives and negatives are found. Summarizing, investigations of the cosmic ray beam up to date have shown the presence of electrons, positrons, protons, photons, neutrons, alpha particles, hydrogen or helium nuclei, and possibly heavy electrons. However, the life history of these rays is still a mystery, and there is no doubt that present day

theories will be greatly modified and extended before the nature of cosmic rays is understood.

Since the energies of the various components of the cosmic ray beam differ, measurements of these energies have been one means of studying their nature. The penetrating power of the entire beam as measured by Millikan (12), is over 500 times the penetrating power of X-rays. Cosmic rays can pass through nearly 18 feet of lead before they are completely absorbed; the most penetrating X-rays cannot go through one-half inch of lead. According to Compton (4), the rays reaching the earth may be divided into two quite definite energy ranges, the lower of which is much more easily absorbed than the higher. Rays of a third energy level which are still more easily absorbed, are not present to any great extent except at very high altitudes.

The most common and direct method of determining the energy of cosmic ray particles is that which depends upon their deflection by a magnetic field. A cloud chamber is placed between the poles of an electromagnet of known strength; the curvature of the paths of the rays may then be studied as a function of the magnetic field. The unit of energy, the electron-volt, is defined as the energy acquired by an electron in falling through a difference of

potential of one volt. Compton (4) has concluded, after much study of experimental evidence, that the energy of primary cosmic rays varies from 2 billion ev to 60 billion ev. The blocking effect of the earth's magnetic field and atmospheric absorption make it necessary for charged particles to have an energy of at least 30 billion ev to reach the earth at the equator (12). The resultant interaction of the magnetic field of the earth and the field due to the moving particle, tends to deflect the particle. The amount of deflection varies inversely with the energy, hence if particles with an energy of 30 billion ev can just reach the surface of the earth at the equator, those of less energy are deflected through a greater angle and miss the earth entirely. But the angle between the lines of force of the earth's magnetic field and the velocity vector of the particle decreases as latitude increases. Since only that component of the magnetic field which is perpendicular to the direction of the particle is effective, the minimum energy which a particle must have in order that it may reach the surface of the earth decreases toward the poles.

Variation in cosmic ray intensity with latitude depends upon the different energies of the charged components, hence a study of these variations should give some clue to

their nature. That the greater part of the observed beam is made up of charged particles is proved by the fact that lines of equal cosmic ray intensity follow very closely the lines of geomagnetic latitude (4). From the equator to 49 degrees, there is a steady increase in intensity which amounts to about 16 per cent of the equatorial value, but at magnetic latitudes greater than 49 degrees there is no significant variation in intensity. This latitude effect is shown by the curve in Figure 1, which was plotted from experimental data by Compton and his associates (3).

Vallarta (26) suggests this definite latitude effect may be due to a "sharp threshold energy of the primary rays, or to deflection of smaller energy particles by the action of the magnetic field of the sun. Consequences of the latter hypothesis include diurnal and annual variations in intensity, whose agreement with observation is questionable."

A further study of Figure 1 shows a rapid increase in ionization with altitude, at any given latitude, indicating the presence of the third energy level component. The ratio of the intensity at the poles to the intensity at the equator also increases with altitude, varying from about 16 per cent at sea level to about 33 per cent at 14,000 feet. Altitude measurements at Peru, one degree removed

Relative
intensity

7

altitude 4360 m.

6

5

4

3

altitude 2000 m.

2

sea level

1

0 10 20 30 40 50 60 70 80 90

Degrees latitude

Fig. 1. Variation of cosmic ray intensity
with geomagnetic latitude.

from the magnetic equator, show ionization at 28,700 feet to be 18 times the sea level value. A curve plotted from data taken by Piccard as reported by Swann (23), when extrapolated to the top of the atmosphere, gives intensity in these latitudes to be about 90 times the sea level value.

Measurements within a per cent or two of the top of the atmosphere were made by Millikan, Neher, and Haynes (13) by means of self-recording instruments sent up in small balloons. Ionization was found to rise exponentially until it reached a maximum at an altitude corresponding to a pressure of 46.6 mm Hg, then fell rapidly as the instruments continued to rise (Figure 2). This same effect was noted at approximately the same height, 57,000 feet, during the stratosphere flight previously mentioned. Both Millikan (13) and Swann (24) interpret this as the level at which the incoming primary rays are in equilibrium with the secondaries produced. As the primaries strike the molecules of the upper atmosphere, the radiation builds up from the top of the atmosphere down to the 57,000 foot level. Below this level, the radiation decreases due to atmospheric absorption.

Horizontal intensity at the surface of the earth is negligible compared with that from the vertical as a result

Intensity
ions/cc/sec

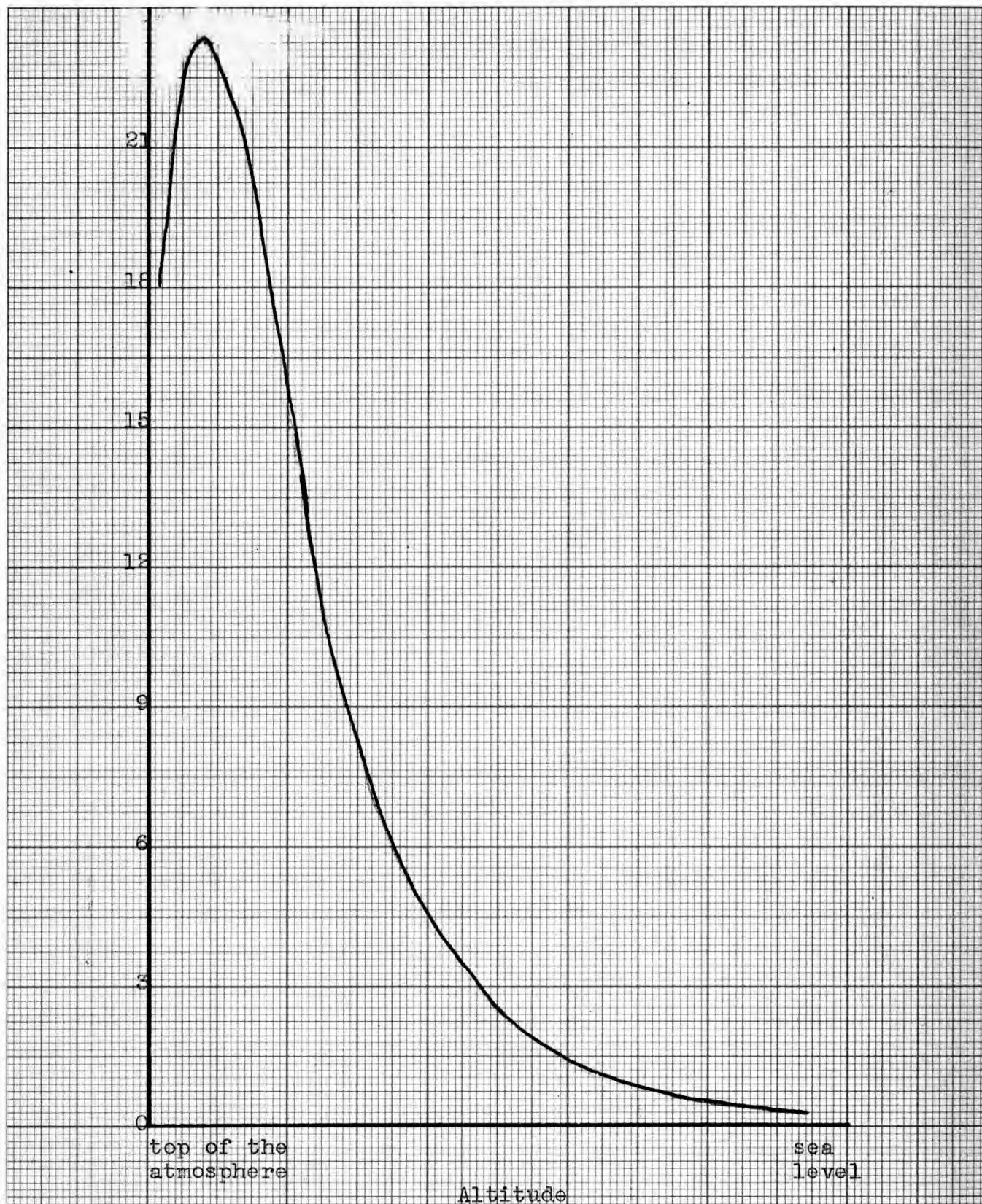


Fig. 2. Variation of cosmic ray intensity with altitude.

of the great thickness of atmosphere which horizontal rays must traverse. At the latitude of Manhattan, about 40 degrees north, the number of rays observed from the horizontal is about 12 per cent the number observed from the vertical. Since the ratio of the horizontal depth of atmosphere to the vertical depth increases with altitude, the ratio of horizontal intensity to the vertical intensity of cosmic rays should decrease with altitude. At 40,000 feet, however, the horizontal intensity was found to be about 20 per cent of the vertical intensity, a value which was higher than expected (24). At 72,000 feet, the number from the horizontal was practically equal to the number from the vertical. Swann concluded from these data that all rays which entered the counter from the horizontal at that height had not traveled all the way through the atmosphere, but had swung around in their paths from the vertical under influence of the earth's magnetic field.

A slight east-west asymmetry in intensity has also been noted recently by several observers (12). All experiments have shown a higher intensity in the northern hemisphere for the radiation coming from the west, indicating a predominance of positively charged particles.

An interesting phenomenon which occurs occasionally is the production of "bursts" of radiation in matter by cosmic rays. These bursts occur at random several times a day, and, according to cloud chamber photographs, appear to consist of electrons, positrons and gamma-rays. The mechanism of burst production is not fully understood. In the simplest explanation it is assumed that an incoming high energy primary transfers its energy into a spray of photons. The photons in turn spend their energy in the production of electrons and positrons. Ramsey (15) believes that at least 75 per cent of all nuclear bursts are produced by photons, not charged particles. In disagreement with this point of view, Sawyer (20) offers experimental evidence which seems to indicate that showers are due to charged secondaries in the cosmic ray beam. Locher (24) has given evidence that at the point where the burst occurs, neutrons are emitted which serve as secondary initiators in disrupting other atoms. Thus the whole phenomenon spreads through the material resulting in the very large burst noted.

Shower production has been found to increase with elevation on the surface of the earth. Montgomery et al (27) found that the frequency increases by a

factor of 26.6 from sea level to Pikes Peak. The rate of increase of number of bursts with altitude does not, however, continue at high altitudes.

Until the constitution of cosmic rays is known, the source can be only a matter of conjecture. An attempt by Das (6) to connect the diurnal intensity variation, which he reports amounts to about 0.2 per cent of the total, with the appearance of Nova Herculis, was later disproved by Barnothy and Forro (1). Some have tried to connect cosmic rays with auroral phenomena, but Eve (8) has pointed out that auroral intensity follows the eleven year periodical variation of sun spots, while cosmic ray intensity does not. Compton (2) predicts a variation with sidereal time. Doan (7) reports a ten-day analysis which indicated a maximum of intensity at about 9:00 A.M. having a magnitude about 0.19 per cent greater than the average. This is, however, insufficient evidence to prove the source of cosmic rays as being within our galaxy.

LeMaitre, as reported by Millikan (12), has suggested that the cosmic radiation was formed at an early stage in the history of the universe and has been traveling in space ever since. Millikan (12) upholds the theory of annihilation of matter--transformation of matter into radiant energy in the process of the building up of complex molecules. This process has

recently been proved possible by transmutation of elements in laboratories. Jeans theory is similar to that of Milikan except in the matter of building blocks; he attributes the origin of the high frequency radiation as the falling together, in interstellar space, of protons and electrons. The large primary neutron component found in the stratosphere is interpreted by Swann (24) as meaning that cosmic radiation has been associated with considerable quantities of matter before reaching the surface of the earth. These hypotheses and others have been offered to explain the origin of cosmic rays, but up to the present time none has been accepted as satisfactory.

The complex and uncertain situation in which investigators still find themselves offers a challenge to science in the disputed questions of constitution and source of cosmic rays.

Methods of Measurement

The three methods thus far used in detecting and measuring cosmic rays are (1) the electrometer and ionization chamber, (2) the cloud chamber, and (3) the Geiger-Meuller counter. All of these methods depend on the ability of cosmic rays to produce gaseous ionization.

Work done

by Rutherford, Townsend, Thomson, and others in the 1890's gave experimental proof that a gas could be rendered conducting by certain ionizing agents, and the theory advanced by them to explain this phenomenon is the one which is still accepted--that of breaking up of the gaseous molecules into ions. If this ionized condition occurs in a gas between electrodes at a high potential the field acts on the ions in such a way that they may carry charges across the space.

The electrometer and ionization chamber shown in Figure 3 (9), are of the type used by Compton and his associates in a world survey of sea level intensities. The bronze and lead shields cut out nearly all radiation except the highly penetrating cosmic. The insulated rod, which is connected to a source of potential, is charged to the desired voltage. As the rod loses its charge to the walls of the bomb due to ionization of the gas within the bomb by a cosmic ray, this loss is recorded by the electrometer which has been calibrated to give the number of ion-pairs formed per cubic centimeter per second at normal atmospheric pressure. Apparatus of this kind is necessarily heavy and consequently not adaptable to stratospheric measurements, but it does have the advantage of giving the total intensity of all the cosmic rays coming

IONIZATION CHAMBER - TYPE USED BY COMPTON

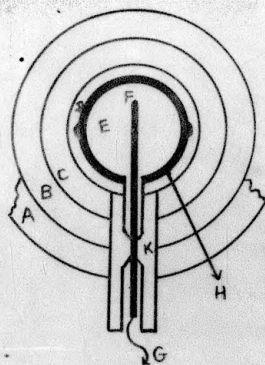


Fig. 3.

- A-B Lead shields
- C Bronze shield
- D Steel Bomb
- E Argon
- F metal Rod
- G To source of potential
- H To electrometer
- K Insulator

WILSON CLOUD CHAMBER

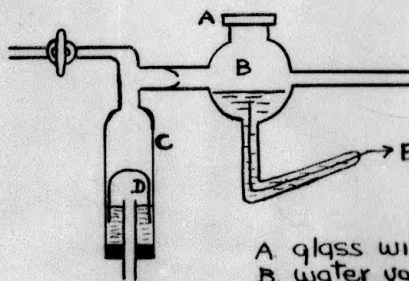


Fig. 4.

- A glass window
- B. water vapor
- C expansion chamber
- D piston
- E To electrometer

to it above the horizontal plane.

A second method of observing cosmic rays involves use of a Wilson cloud chamber similar to the one shown in Figure 4. Sudden adiabatic expansion of the saturated vapor in the chamber causes condensation of the vapor upon the gaseous ions which have been released by cosmic rays. This expansion is brought about by connecting the closed space beneath the piston D to an evacuated space, causing the piston to drop. If a beam of light is directed into the chamber, the trail of liquid drops may be observed or may be photographed by reflected light. In photographing the tracks, two stereoscopic pictures are usually made simultaneously in order that the path may be reconstructed in space. An intense magnetic field applied at right angles to the path, causes a curvature of the path which is proportional to the momentum of the ray. An electric field is applied in the chamber to sweep out the ions after each expansion. If it is desired to operate the cloud chamber only when a particle passes through, the expansion may be controlled by the discharge of coincidence counters (described in the following paragraph) placed above or below the chamber. If the time lag between discharge of the counters and expansion of the cloud chamber is not greater than 0.01 second, the tracks will be distinct.

The cloud chamber method of study may give a permanent record of the investigation, and shows the number of positives, negatives, and bursts. It was by this method that Anderson (30) discovered the positron.

Apparatus Used in This Investigation

The third method for detecting cosmic rays--that used in this investigation--is the coincidence tube counter method originally used by Rutherford and Geiger in 1908 in a study of gaseous ionization. The apparatus and circuits of the improved form designed by Geiger and Meuller, are shown in Plate 1 and Figure 5. The tubes (A, B, and C, Plate 1) are of thin-walled pyrex glass inside of which fit thin copper cylindrical cathodes; the anode is a tungsten wire sealed in the axis of the cylinder. These tubes, with detector tubes (6C6, Figure 5) and resistors, fit into the aluminum housings. Either the shorter, single tube (C, Plate 1) or the two longer tubes (A and B) which are connected in series, may be used for detection of ionizing radiations. The single tube will detect radiations from any direction and may be used in counting radioactive emanations. An ionizing ray must traverse both the longer tubes and cause simultaneous discharge before the impulse will be

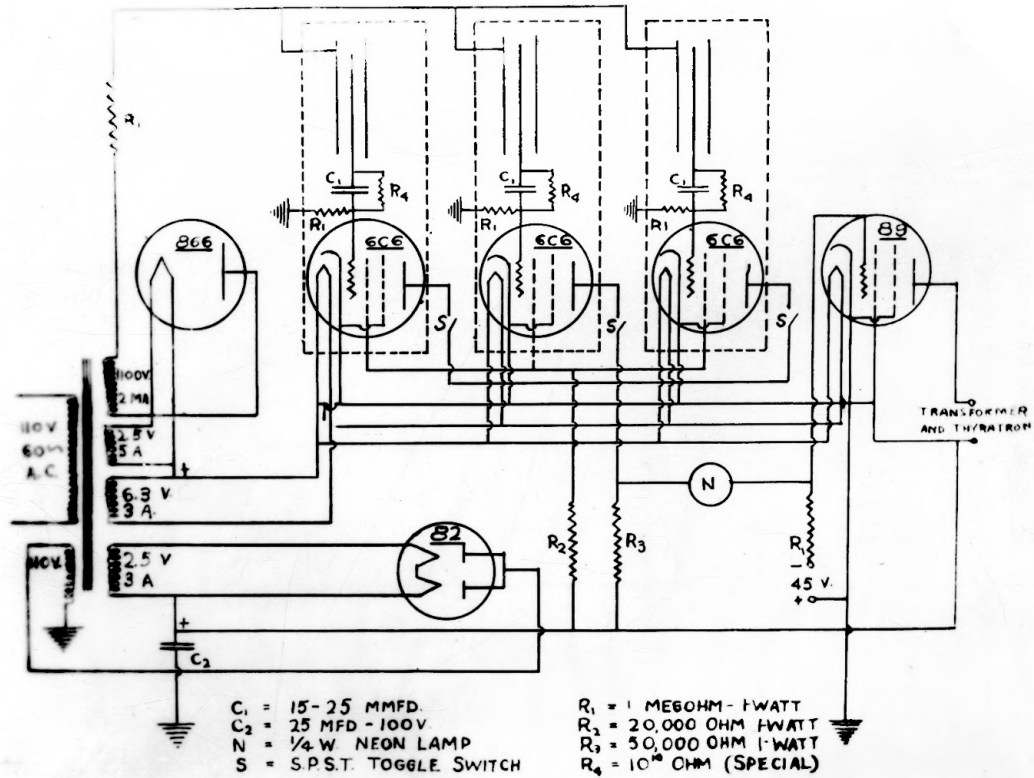
Explanation of

Figure 5

Wiring diagram of

Geiger-Meuller counter

Figure 5



Explanation of

Plate 1

Geiger-Meuller counter,
amplifier, and chronograph.

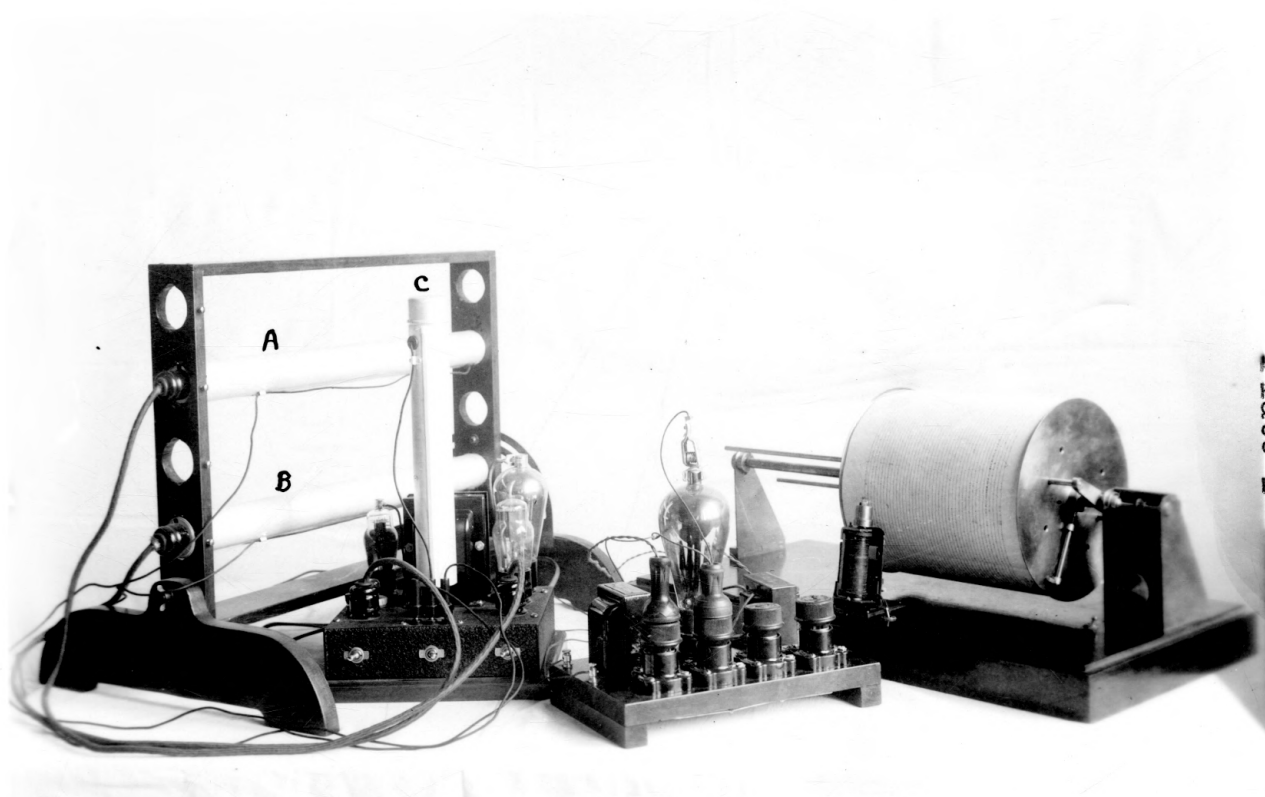


Plate 1

recorded (Figure 5). No known radiations other than cosmic rays have sufficient energy to penetrate both tubes. The apparatus operates from a 60 cycle, 110 volt power supply with a number 866 rectifier tube as shown in Figure 5. A high potential of about 1100 volts is maintained across the tubes. When the inert gas in the tubes becomes ionized, the ions produced are acted upon by the intense field and produce more ions by collision. This cumulative process increases the current until it may be detected by several methods--visibly by the glow of a small neon bulb (N, Figure 5) or by an electrometer, or audibly by a loud speaker or a counting relay.

In using the Geiger-Meuller coincidence counter for cosmic ray study, the two long tubes are arranged horizontally, parallel to each other. The plane of the axes can be changed in order to make the instrument directionally sensitive. It was possible to obtain three values of sensitivity by changing the distance between the axes of the tubes. The greater the distance between axes, the smaller the angle from which a ray may enter both tubes (Figure 6). This method gives the total number of ionizing radiations coming from a limited direction, but no evidence as to their nature or as to whether they are primary or secondary.

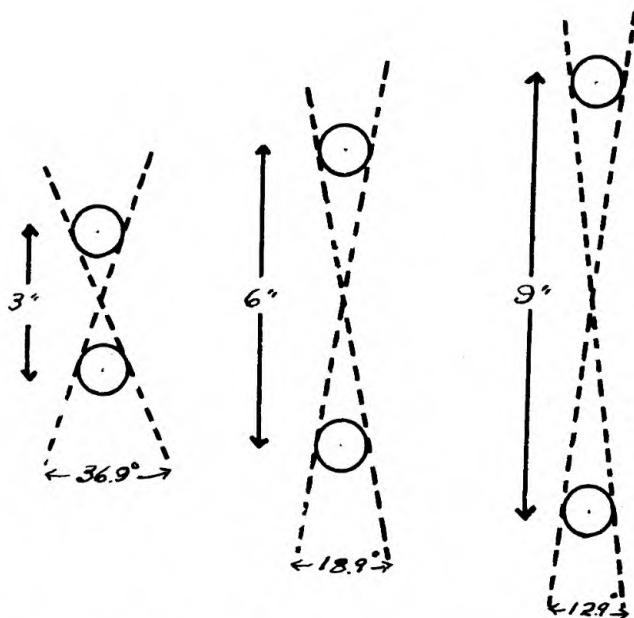


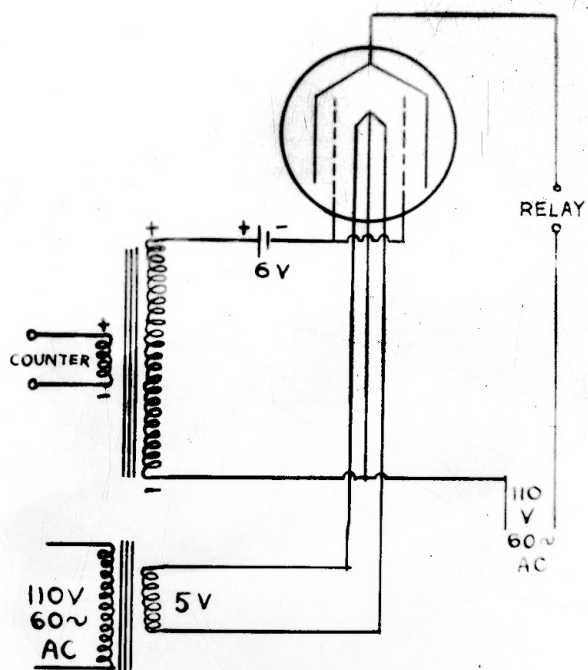
Fig. 6. The angle from which cosmic rays enter both Geiger-Mueller counter tubes may be decreased by increasing the distance between axes of the tubes. Since a ray must traverse both tubes in order to be recorded, decreasing the angle increases directional sensitivity of the instrument.

The first investigations were made by means of loud speaker detection. For further study the tubes were connected to the amplifier and chronograph and allowed to operate continuously. The impulse from the amplifying tube (89, Figure 5) was brought to the grid of a General Electric type FG--57 thyatron through a transformer and a bias according to Figure 7. A FG--57 tube will record impulses up to a frequency of 100 per second, since ionization time is 10 microseconds and deionization time is 1000 microseconds. Plate current from the thyatron operated the electromagnet to which was fixed the pen of the chronograph.

Explanation of

Figure 7

Thyratron amplifier
circuit



Figuro 7.

Thus each impulse was permanently recorded.

The cronograph shown by photograph in Plate 1, was designed and constructed for this investigation. The drum, driven by a 5-watt synchronous motor, made two revolutions per hour on a rod threaded with a 4 millimeter pitch. An 8 inch diameter and a 9 inch length allowed 0.837 inch per minute for recording impulses over a twenty-four hour period. The impulses were marked by a stainless steel capillary pen supplied with mercurochrome from an ink well fixed to the electromagnet. An actual twenty-four hour chronograph record is shown in Figure 8.

Experimental Results

The counts made by loud speaker detection were necessarily taken over short periods of time during the afternoon hours in a room above which were three six-inch reinforced concrete floors. The results are tabulated in Table 1. All measurements except the last were made with the axes of tubes in a north-south direction, and with three inches between axes. When the plane of the tubes was at an angle of 75 degrees above the horizontal, both east and west impulses show a higher average per minute than from the vertical. This result cannot be accepted as

Explanation of

Figure 8

Twenty-four hour
chronograph record

Sunday June 6 (out of doors, 45° west)
10:30 AM.

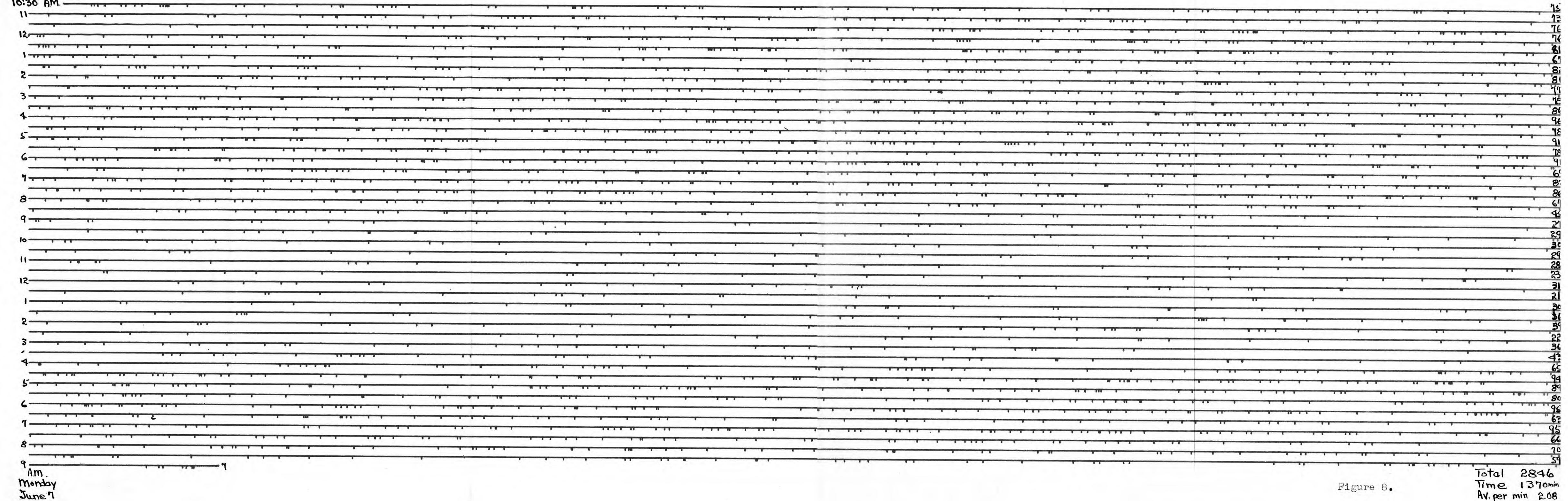


Figure 8.

of much significance, however, because of limited data.

Table 1. Results by loud speaker detection as explained above.

				:	
				:	
Angle above				:	Ave. per
horizontal				:	min.
				:	
1	5	degrees	W		.406
2	20	"	W		.875
3	35	"	W		1.32
4	50	"	W		2.25
5	50	"	E		3.41
6	75	"	W		3.53
7	75	"	E		3.31
8	90	"			3.24
9	90	"			3.23

The following tables show the data taken by continuous operation of the Geiger-Meuller counter and chronograph. The position of the tubes is given above each table.

Table 2

Results of a sixteen day period with the tubes indoors in a vertical position, north-south direction, and six inches between axes.

Date	Total count	Total minutes	Average per min.
May 6	2912	1410	2.07
" 7	3043	1350	2.25
" 8	3130	1380	2.27
" 9	2754	1260	2.34
" 10	1487	720	2.04
" 11	2884	1230	2.34
" 12	2686	1260	2.12
" 13	2833	1290	2.20
" 14	3799	1695	2.24
" 15	3312	1305	2.54
" 16	3365	1290	2.61
" 17	3610	1650	2.19
" 18	3139	1260	2.49
" 19	3726	1650	2.26
" 20	2744	1170	2.35
" 21	3015	1320	2.28
Mean average per minute			2.29

Table 3

Results of a seven day record with the tubes out of doors in a vertical position, north-south direction, and with six inches between axes.

Date		Total	Total	Average
		count	minutes	per min.
June	15	4368	1440	3.03
"	16	4766	1440	3.24
"	17	4696	1440	3.26
"	18	4297	1440	2.98
"	19	3900	1380	2.72
"	20	3921	1440	2.72
"	21	3479	1470	2.37
Mean average per minute				2.90

Table 4

Results of a fourteen day record with the tubes indoors at an angle of 45 degrees west, north-south direction, and with six inches between axes.

Date		Total count	Total minutes	Average per min.
May	22	2478	1560	1.59
"	23	2683	1320	2.03
"	24	2446	1440	1.70
"	25	2585	1440	1.80
"	26	2337	1440	1.62
"	27	2390	1440	1.66
"	28	2277	1470	1.25
"	29	2198	1440	1.53
"	30	2806	1470	1.92
June	1	2290	1440	1.60
"	2	2620	1470	1.78
"	3	2342	1470	1.59
"	4	2361	1470	1.61
"	5	1930	1260	1.53
Mean average per minute				1.66

Table 5

Results of a ten day record with the tubes out of doors at an angle of 45 degrees west, north-south direction, and with six inches between axes.

Date		Total	Total	Average
		count	minutes	per min.
June	5	3760	1410	2.18
"	6	2846	1370	2.08
"	7	2724	1440	1.89
"	8	1602	1260	1.62
"	9	1794	1410	1.27
"	10	2505	1475	1.70
"	11	2063	1440	1.41
"	12	2705	1440	1.88
"	13	3017	1440	2.10
"	14	2412	1410	1.71
Mean average per minute 1.78				

Table 6

Comparison of mean average per minute at different angles.

Position of tubes			Mean ave./min.
90 degrees		indoors	2.33
90	"	out of doors	2.90
45	"	W indoors	1.66
45	"	W out of doors	1.78

The complete data were plotted on continuous curves to show the relation between the number of impulses and the time of day. Since the period for one revolution of the chronograph was one-half hour, it was convenient to plot the total number during half-hour intervals against time of day. These plots are shown in Figures 9, 10, 11, and 12. The counter tubes were in a north-south direction with six inches between axes during the entire time represented by the curves.

A study and comparison of these curves and the accompanying data reveals the following:

1. With the tubes in a vertical position, the average number during half-hour intervals was higher out of doors than indoors (Figures 9 and 10).

2. With the plane of the axes of the tubes at an

angle of 45 degrees west of vertical, the average number during half-hour intervals was higher out of doors than indoors (Figures 11 and 12).

3. The weather from about noon June 8 until about noon June 12 was cloudy and rainy. The curve (Figure 12) shows a decrease in number on those days.

4. A sharp decrease in number between the hours of 9:30 P.M. and 3:30 A.M. was noted at all angles when the tubes were out of doors (Figures 10 and 11). A limited amount of data were taken out of doors with the tubes at 45 degrees east, and horizontal. These records also show minima which occur at the hours indicated above. No such minima were observed when the tubes were indoors (Figures 9 and 11).

5. A comparison between the cosmic ray count and barometric pressure records shows no apparent relation. The pressure records are on file in the office of the Department of Physics.

6. The intensity of the impulses is more uniform out of doors than indoors. This was more evident in the loud speaker observations than it is on the chronograph records.

7. The appearance of "northern lights" about 11:00 P.M., May 18, had no apparent effect on the cosmic ray count (Figure 9).

8. Cosmic rays seem to arrive at random. There is no noticeable periodic occurrence (Figure 8).

Conclusions

The increase in number of cosmic rays recorded with the tubes out of doors indicates absorption by the walls of the building. An excess amount of moisture in the atmosphere also has an absorbing effect.

Greater variation in intensity of impulses recorded indoors may be due to a small secondary production in the walls of the building.

The definite minima which occur during the night indicate that the surplus radiation out of doors during the day is due to a low energy component which can not penetrate the walls of the building. The apparent presence of these minima is by far the most significant result of this work. No other observer has reported such marked diurnal variation.

Explanation of

Figure 9

Curve showing data
taken with counter tubes
vertical, indoors

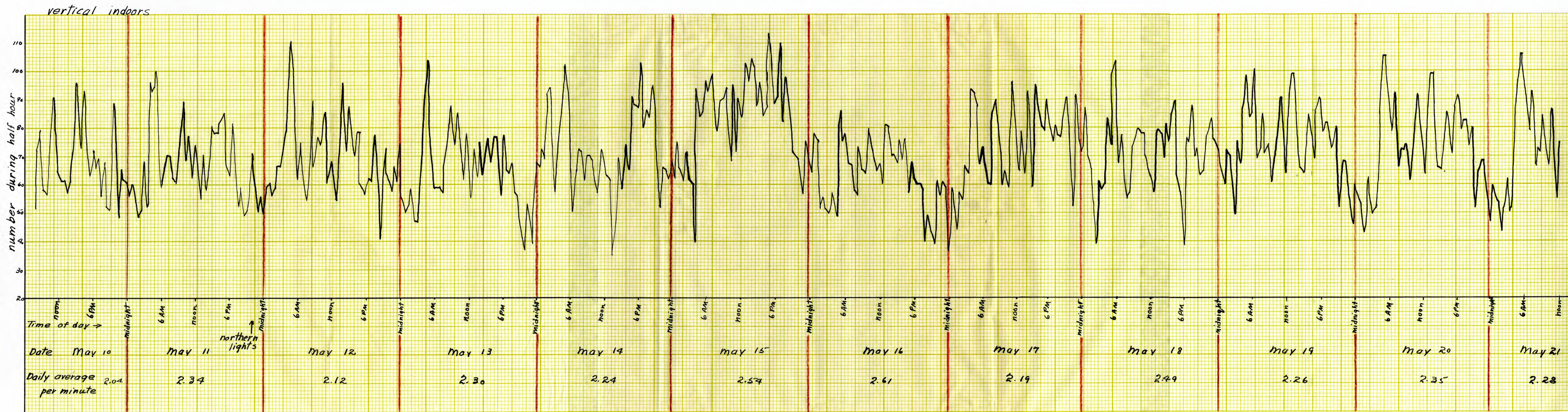


Figure 9

Explanation of Figure 10

Curve showing data taken with
counter tubes vertical, out of doors

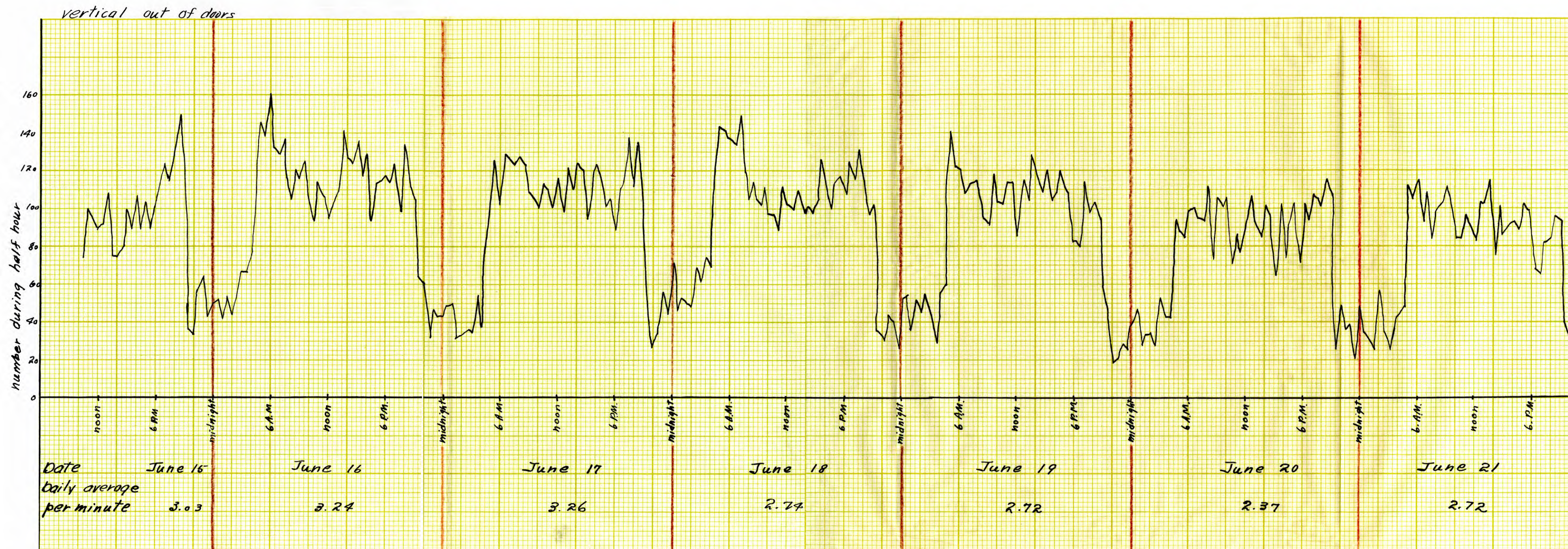


Figure 10

Explanation of

Figure 11

Curve showing data
taken with counter tubes
45 degrees, indoors

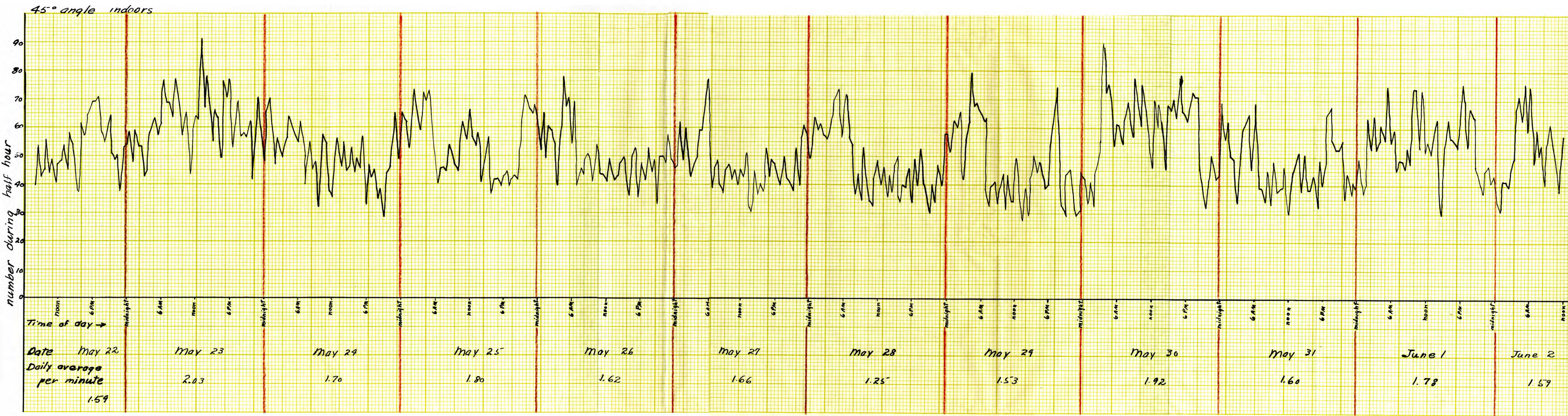


Figure 11.

Explanation of

Figure 12

Curve showing data
taken with counter tubes
45 degrees, out of doors

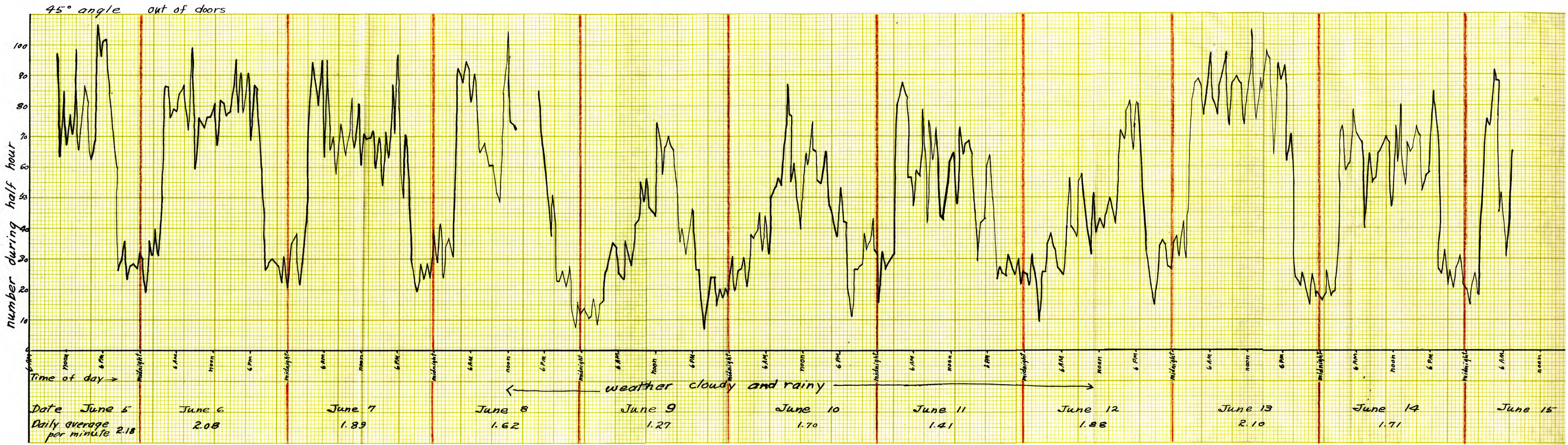


Figure 12.

LENARD RAYS

When current driven by a high potential passes through a gas at low pressure, rays are found to be projected from the cathode. Crookes, among the first to experiment on the mechanical properties of cathode rays, suggested in about 1879 that they were "radiant matter in the fourth state." Lenard, in 1893, succeeded in passing the rays through an aluminum window in a cathode ray tube. He declared them, on the strength of their absorption, to be composed of "ether waves." However, there was a great mass of evidence brought forth in the next five years in favor of the "material particle" theory. The question was decided in 1898 when Thomson proved that the elements of the cathode ray stream were electrons, and proceeded to measure the charge and mass of a unit. These facts forced Lenard to change his opinion, but cathode rays which are projected outside the tube, are still termed "lenard rays", to distinguish them from rays inside the tube.

Coolidge (29), in 1925, built a high vacuum high voltage hot cathode tube of the Lenard type but with much improvement in the number and speed of electrons projected from the tube. The anode of the Coolidge tube was a nickel

window 8 centimeters in diameter and 0.0254 millimeter in thickness. This window, supported by a molybdenum honeycomb structure, transmitted the high velocity electrons to the outside of the tube.

This investigation was planned as a study of the production and effects of Lenard rays on different substances. The tube and high vacuum pumping system were assembled for this purpose. The objects of study were placed in the path of the electrons from this tube, bombarded for a definite length of time, then examined for changes which may have taken place. Many of the substances under experiment were tested for alpha and beta radiations by use of an ionization chamber designed and constructed for this purpose.

Apparatus Used in This Investigation

A schematic diagram of the Lenard tube used in this investigation is shown in Figure 13. A type 7B General Electric X-ray cup cathode was sealed in the bottom of a two-liter pyrex flask and held firmly in place by a mica support. The anode, a nickel window of 0.003 centimeter thickness, and a supporting screen, also of nickel, were soldered to a brass ring. The brass ring was then cemented

over the mouth of the flask with Picein wax. The anode was cooled by means of water which flowed through a copper tube soldered directly to the brass ring.

In order to create the low pressure necessary for operation, this tube was connected to a high vacuum pumping system of the oil diffusion type shown in Figure 14 and Plate 2. Apiezon oil, a highly refined organic compound with vapor pressure of 10^{-7} at room temperature, was vaporized by heat from an electric furnace placed below the boiler. The oil vapors flowed through the main chamber of the pump, condensed and returned to the boiler through J, Figure 14. A water cooling system (E-F, Figure 14) produced rapid condensation in the diffusion chamber. The vapor pump was backed by a Cenco Hyvac forepump. With a potential of 70,000 volts across the tube no appreciable glow was present, indicating that the pressure obtained was 10^{-6} mm Hg or better.

The charcoal trap between the Lenard ray tube and the high vacuum pump prevented diffusion of oil vapor into the tube where there was a possibility of reaction with metal parts. The second charcoal trap prevented mixing of oil vapor from the forepump with the light Apiezon oil. The action of these traps depends on the adsorbing power of the charcoal. It was therefore necessary to activate the

CATHODE RAY TUBE

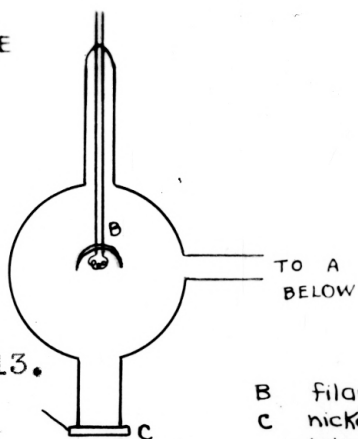


Fig. 13.

B filament
C nickel window

HIGH VACUUM PUMPING SYSTEM

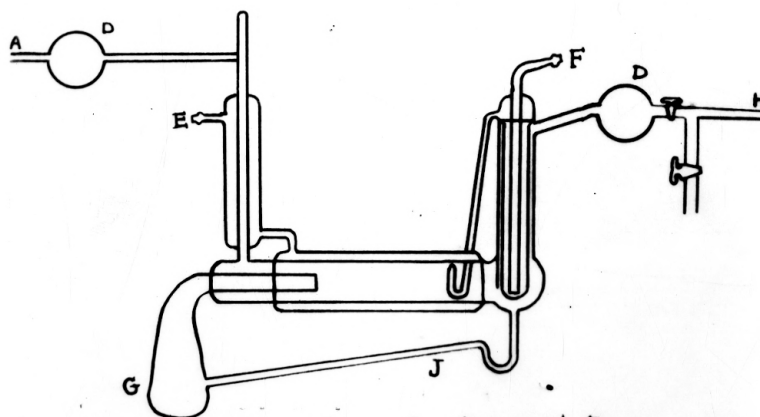


Fig. 14.

D charcoal traps
E-F water cooling system
G boiler
H to forepump

charcoal by occasionally heating for several hours at a temperature of about 400 degrees Centigrade. This baking-out process was done by electric ovens built around the traps. The temperature of the ovens, controlled by resistances in series, was determined by chromel-alumel thermocouples. The thermal electromotive force was measured by a potentiometer and the temperature equivalent read from tables furnished by the manufacturers of this thermocouple alloy. The complete apparatus is shown in Plate 2.

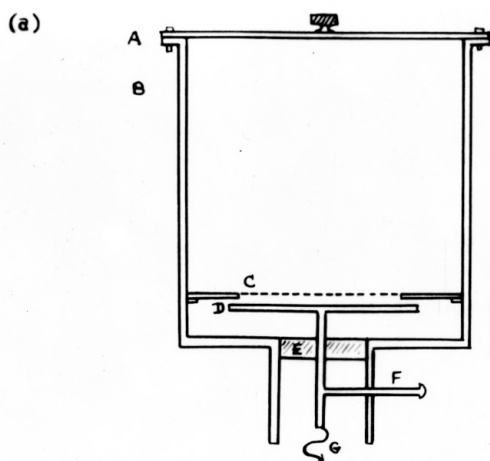
The source of high potential for accelerating the electrons was a mechanical rectification X-ray generator capable of producing 100 kilovolts. This generator consisted essentially of a transformer to produce high voltage and a rotary rectifier for making this voltage unidirectional. For the greater part of this investigation, the potential difference was 80 kilovolts.

The greater advantage of a Coolidge type tube over the older Lenard type lies in the accurate control of the intensity of the beam of electrons. Since the electrons in the Coolidge type tube originate as thermions from the hot cathode, the intensity may easily be controlled by inductance in series with the a.c. source. In the apparatus used for this investigation the filament was heated

by the secondary of a 110-6 volt transformer which had a variable inductance in series with the primary.

In order to test for radiations from the substances which were bombarded by electrons from the Lenard tube, an ionization chamber, schematically diagrammed in Figure 15, was designed and constructed. All the essential dimensions are shown in Figure 15. For study of alpha rays, the lid A may be replaced by (b). The chamber may be inverted and the radioactive material placed on the movable plate I, inside the chamber. The distance between I and D may be controlled by means of a threaded rod. A pointer on the end of the threaded rod indicates this distance directly on the millimeter scale H. By removing the gauze wire screen in the chamber, the lid (b) may also be used for measurement of total ionization. For study of beta rays, the lid A may be replaced by (c). Alpha particles may be excluded by the tinfoil L over the opening in the center of this lid if the source is outside the chamber, thus the only effect measured is that produced by the beta and the gamma rays. The solid brass lid A will exclude both alpha and beta radiations if the active material is outside the chamber. Thus the ionization produced by the gamma rays may be distinguished from that produced by the beta rays. This apparatus was designed especially for use with a Wulf electrometer, and fit on the electrometer in such a manner

IONIZATION CHAMBER



- A Lid which may be replaced by (b) or (c)
- B Ionization chamber - diameter, 12 cm - depth, 12 cm
- C Gauze wire screen - diameter, $7\frac{1}{2}$ cm.
- D Plate - diameter, 8 cm.
Distance between plate and screen, 2 mm
- E Bakelite insulator
- F To source of potential
- G Phosphorbronze wire to electrometer
- H millimeter scale
- I movable plate to carry radioactive substance
- K Lid with tinfoil, L, over center opening

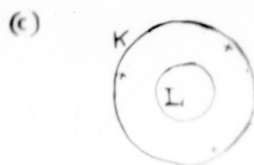
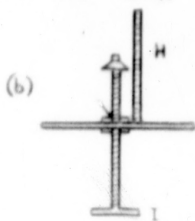


Figure 15.

that the combination could be inverted when necessary (plate 3).

The Wulf electrometer, a German made instrument, consists chiefly of two platinum threads stretched very close together between two conductors. When these threads become charged they repel each other. The distance of separation, which is determined by a telescope and scale, is a measure of the stress existing in the threads. The separation as a function of the potential is shown by the sensitivity curve in Figure 16.

The loss of charge of an electrometer even in the absence of any ionizing source, is known as "natural leak." This is due to residual ions in the atmosphere, and a possible leak across the surface of the insulation. This natural discharge as a function of time is shown by the curve in Figure 17. In all measurements the change in deflection was noted during a one-minute interval. The change in deflection due to natural leak is a direct function of the charge. It was therefore necessary when measuring strength of ionization of active substances to make correction for natural leak.

Plate 2
Lenard ray tube
and
high vacuum pumping system

Plate 2

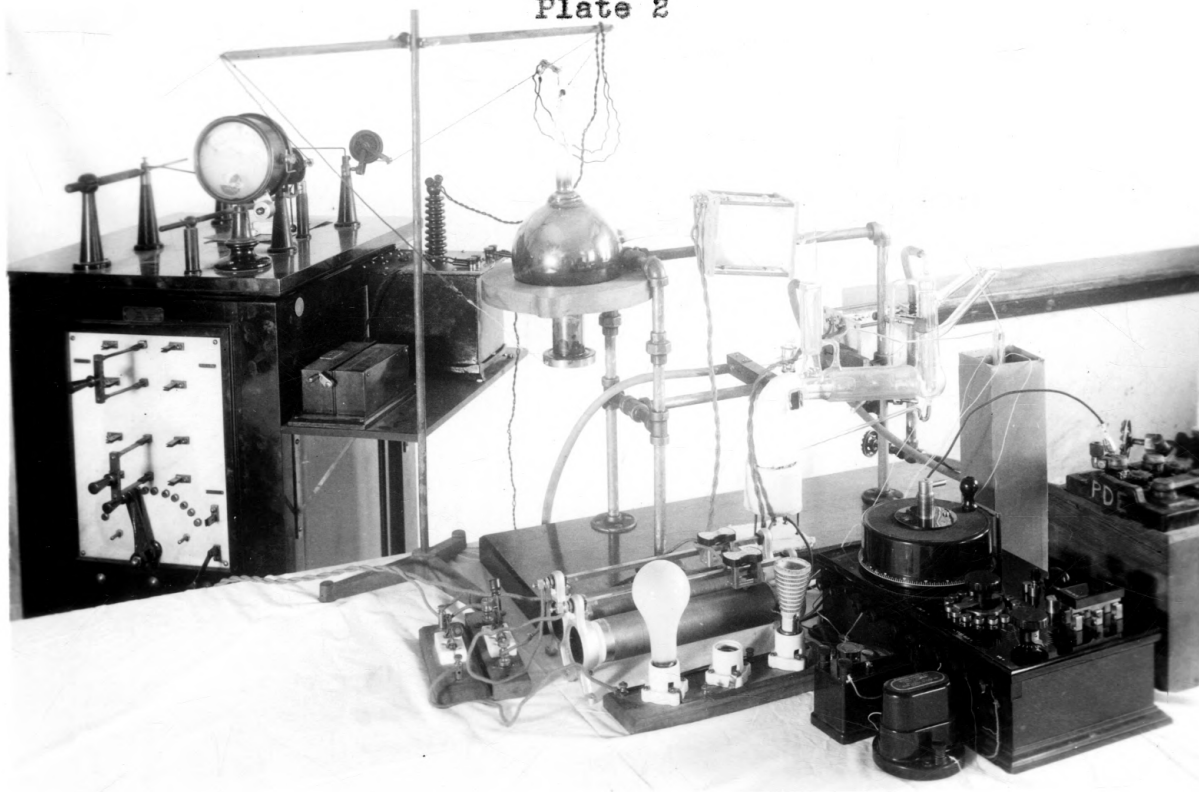
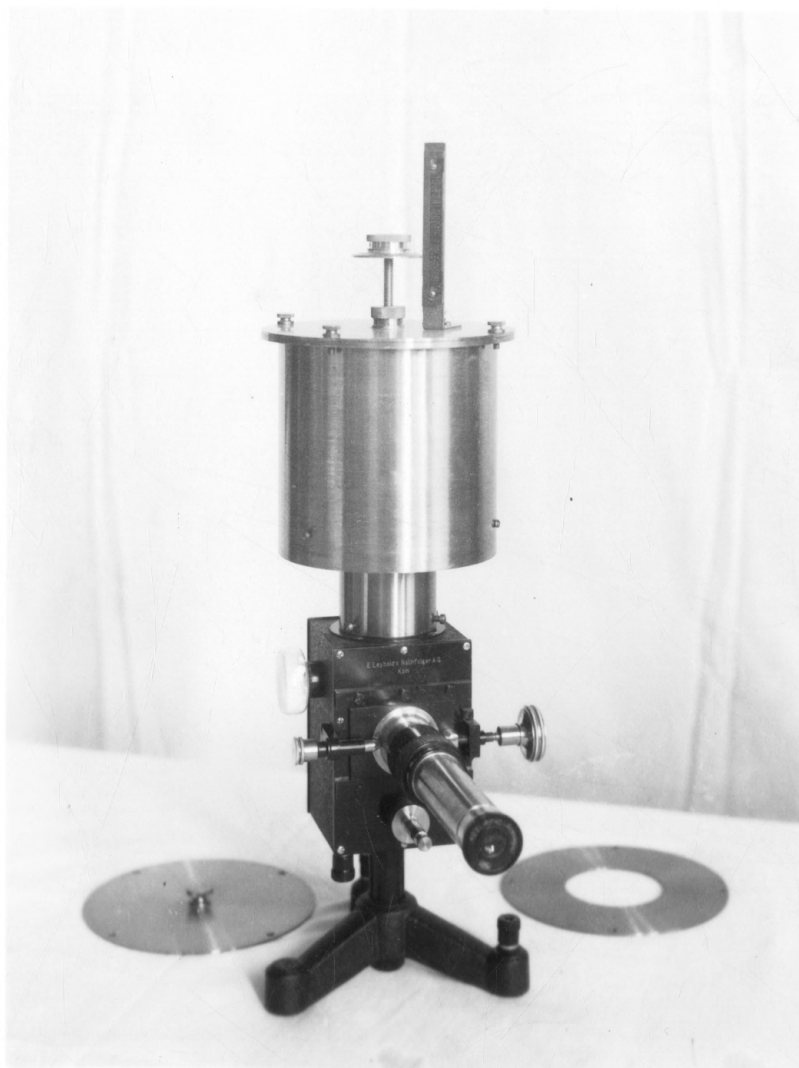


Plate 3
Ionization chamber
and
Wulf electrometer

Plate 3



Deflection
in mm/min

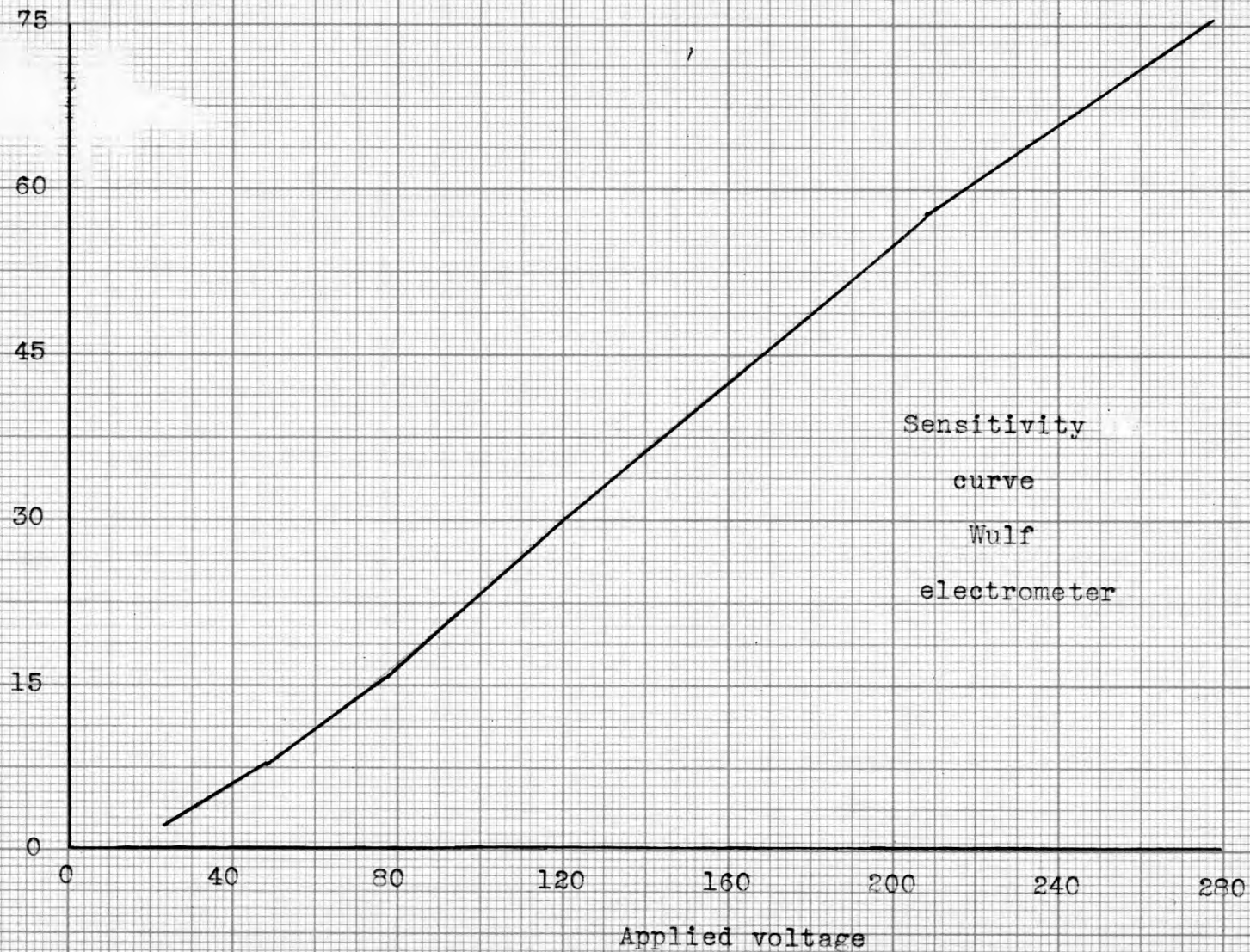


Figure 16.

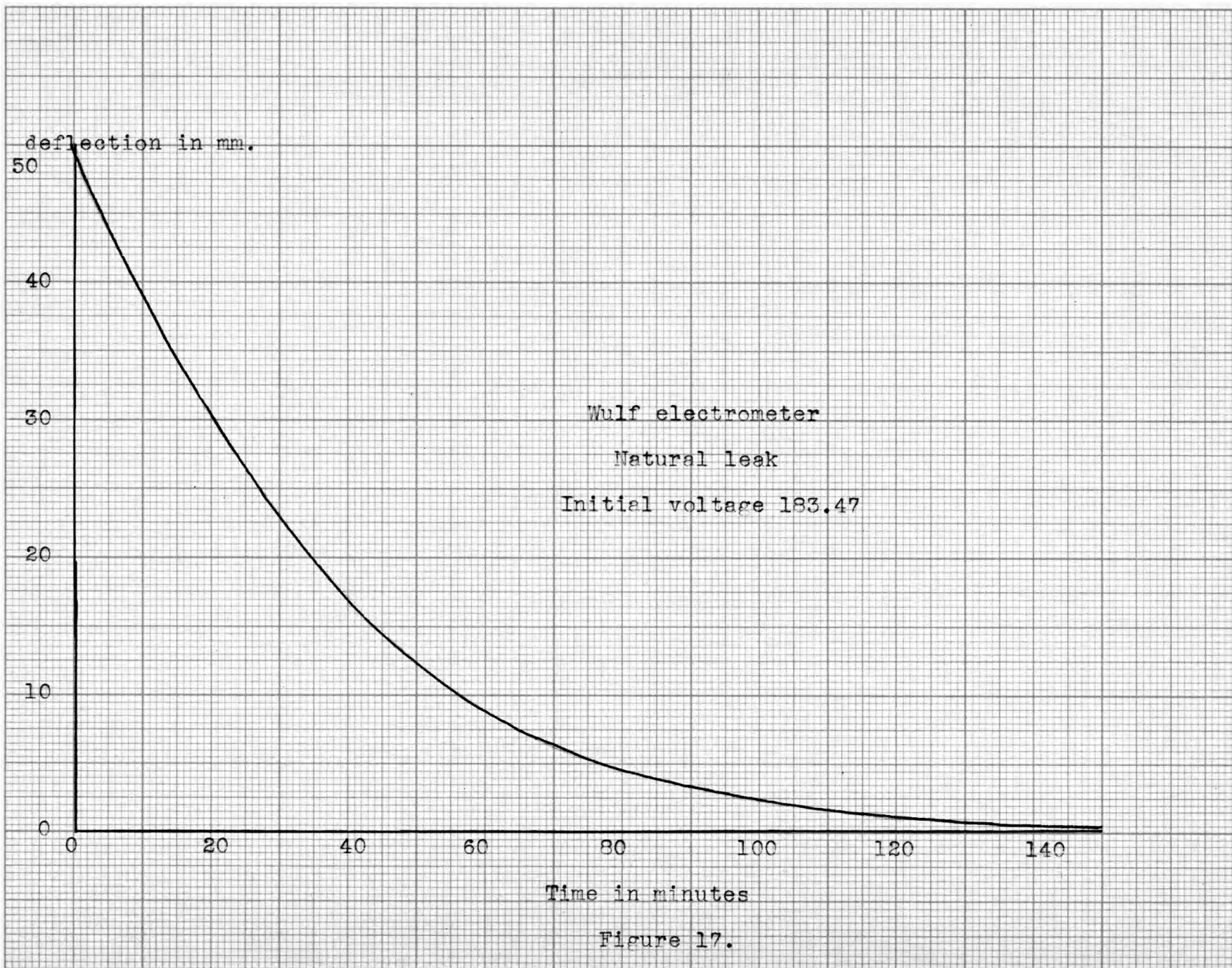


Figure 17.

Experimental Results

Before use in testing for radiations produced by Lenard rays, it was necessary to check the accuracy of the ionization chamber. This was done by measurements made with two samples of ionium of known alpha-range and relative strength. These samples were obtained from the Bureau of Standards at Washington, D. C.

The "range" of an alpha particle is defined as the distance from the source at which ionization due to alpha rays becomes zero. In this experiment the range was determined by placing the ionium on the movable plate I (Figure 15) inside the ionization chamber and varying the distance between the ionium and the charged plate D. With the distance of separation less than the range of the alpha particles, the plate D lost its charge rapidly due to ionization by alpha rays. The curve in Figure 18 shows how the corrected change in deflection varied with distance. The observed points on the curve when the separation of I and D approached the range of the particles, fall very closely on a straight line. Extrapolation of this line to the axis gives the actual distance at which ionization would fall to zero if the bundle of rays were homogeneous. The shape of

Discharge
in mm/min
corrected for
natural leak

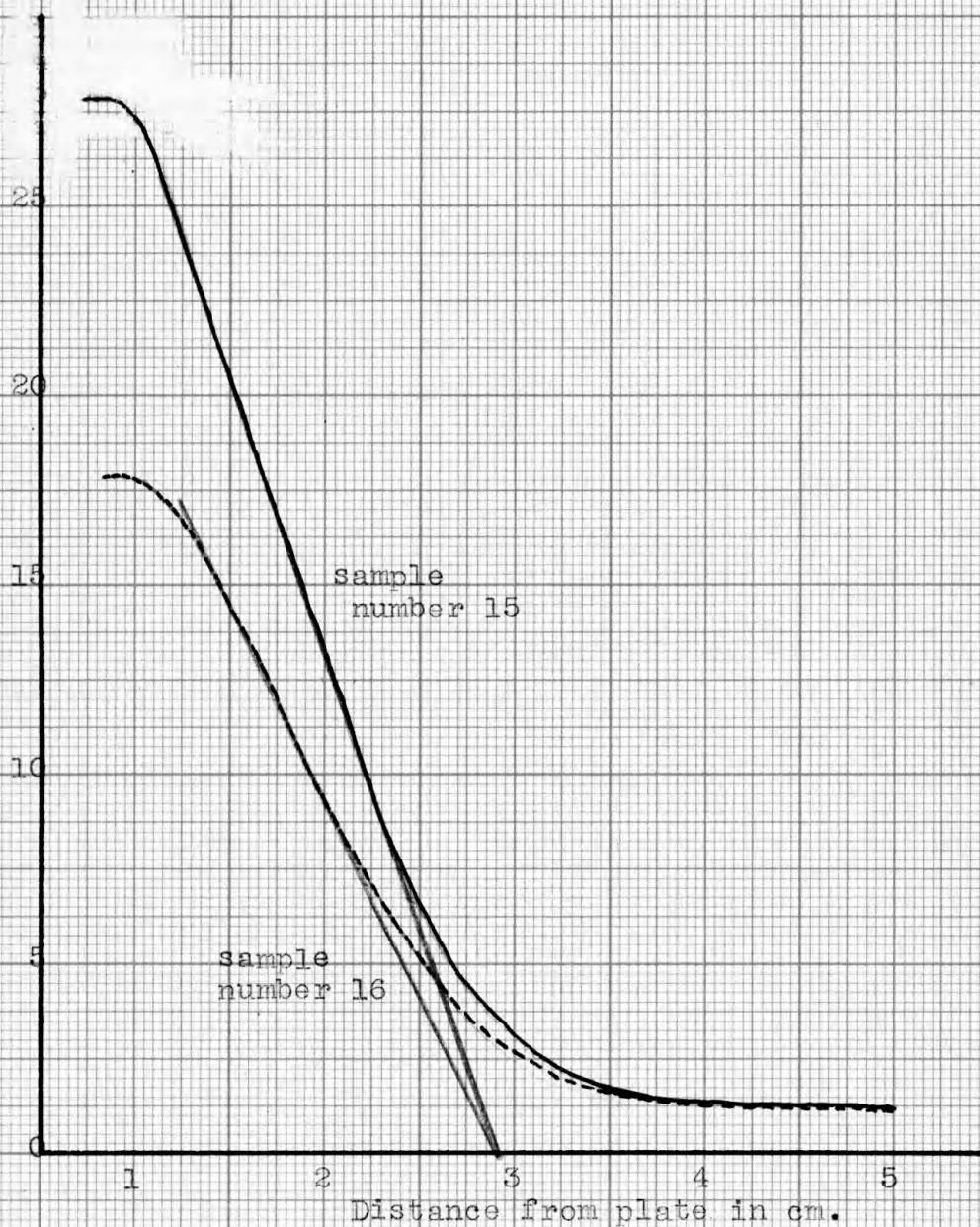


Fig. 18. Alpha-ray ionization by two samples of ionium.

The curve at the end of the range is influenced by the fact that the end of the cone of rays is spherical in shape, while the plate is flat; thus the effect of all particles is not recorded toward the end of the range. The value 2.90 centimeters obtained for the range of these samples of ionium agrees very closely with the accepted value 2.85.

The relative strength of alpha ray ionization of the two samples of ionium was calculated from the data which are plotted in Figure 18, and is shown in Table 7.

Table 7.

Distance source to plate	:	Discharge sample 15	:	Discharge sample 16	:	Ratio sample 15/16
1.25	:	24.75	:	16.75	:	1.47
1.50	:	20.50	:	14.50	:	1.41
1.75	:	17.50	:	12.00	:	1.46
2.00	:	13.00	:	9.25	:	1.40
2.25	:	9.75	:	7.25	:	1.35
2.50	:	6.50	:	3.50	:	1.30
2.75	:	4.50	:	3.50	:	1.30
Average						1.39

The average of values calculated at several different distances was accepted as the relative strength of the two samples. Our calculated value 1.39 agrees fairly well with the value 1.23 given by the Bureau of Standards.

Relative strength of the two samples was checked further by removing the gauze wire screen from near the plate D and observing total ionization in the entire volume of the chamber. The corrected rate of discharge plotted against distance between the source and the charged plate is shown in Figure 19. Since ionium emits no rays other than alpha, the relative strength of the two samples can be calculated from these data. The values are shown in Table 8.

Table 8.

Distance source to plate	:	Discharge samples	:	Ratio samples
	:	15	16	15/16
4.0	:	51.75	37.50	1.38
4.5	:	49.00	36.25	1.35
5.0	:	55.25	34.50	1.32
5.5	:	42.00	32.25	1.29
6.0	:	37.75	29.75	1.29
6.5	:	34.00	27.25	1.30
7.0	:	30.00	24.50	1.26
7.5	:	26.50	20.75	1.32
8.0	:	22.50	17.25	1.34
8.5	:	18.50	13.25	1.38
Average				1.33

The average value 1.33 also agrees quite closely with the accepted value 1.23.

Discharge
in mm/min
corrected for
natural leak

60

50

40

30

20

10

sample number 15

sample
number 16

0

2

4

6

8

Distance from plate in cm.

Fig. 19. Total ionization by two
samples of ionium.

The substances investigated were placed below the anode of the Lenard tube in the path of the high velocity electrons and bombarded for a definite length of time. Since the range of electrons from this tube is 6.2 centimeters*, it was necessary to have the objects within this distance of the anode.

Sodium chloride changed color, first to yellow then to brown, during a thirty minute exposure at a distance of 1.5 centimeters below the anode. This color faded in a few hours. Evidence previously collected by other investigators has shown radioactivity induced in sodium chloride by 200 kilovolt electron bombardment**. The sodium chloride used in this investigation was tested for emanations both by the ionization chamber and electrometer, and by the single tube of the Geiger-Meuller counter. No evidence of the emission of any ionizing particles was observed.

Potassium chloride, bombarded for thirty minutes in a watch glass 1.5 centimeters from the anode showed a color

*The "range", that distance through which electrons will travel through air, depends on the energy with which they leave the anode. The range is therefore a direct function of the potential and may be calculated from the following equation from Slack:

$$\text{Range in cm.} = (100 \times \text{Kv} \times \text{thickness of anode in cm.}) - 17.8$$

**Information Bulletin, Westinghouse Lamp Co. June, 1936

change from white to purple, which faded in a few minutes. Beta radiation emitted from potassium chloride after bombardment reported by other investigators (** Page 58) was not in evidence in our experiment. The potassium chloride was also tested by use of both the ionization chamber and electrometer, and the Geiger-Meuller counter.

Elm leaves deteriorated after a 2 minute exposure to the electrons 1.5 centimeters below the anode. Examination under a microscope showed that the cells were destroyed and the veins blackened.

A grasshopper was paralyzed temporarily by a 3 minute bombardment about 2 centimeters from the anode, but there was no apparent permanent effect.

Sugar water became thick and sirupy after 30 minutes exposure at a distance of 1.5 centimeters.

The surface of a celluloid card became definitely marked with grooves and small pits after 15 minute bombardment at a distance of 1 centimeter.

Small spots appeared on a thin sheet of mica placed in the path of the electrons 1 centimeter from the anode for 15 minutes.

Previous investigators (** Page 58) have reported formation of an insoluble compound from castor oil, and change

of starch to acid. Neither of these effects was observed in our case after a 20 minute bombardment at a distance of 1.5 centimeters.

A change in color and texture of the hair of rabbits has also been reported (** Page 58). In our work, a black rat was exposed for three minutes at a distance of 4 centimeters from the anode. Five days after exposure no change could be observed. This effect may become evident later.

Conclusions

High velocity electrons from an 80,000 volt Lenard tube have sufficient energy to cause changes in some substances. These changes may be either molecular or atomic. Live cells are destroyed. The fact that results in this investigation differ from previous reports is probably due to the lower accelerating potential used with our tube. Most of the other investigations have been made with 200,000 volt Lenard ray tubes.

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